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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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FABRICATION AND FIELD EVALUATION OF A HIGH-CAPACITY, HIGH-EFFICIENCY CHARGE AIR FILTER SYSTEM FOR ARMY AIRCRAFT

Task 9R38-01-017-45

Contract DA 44-177-TC-495

November 1961

62-1-5
NOX

prepared by :

FRAM CORPORATION
Providence, Rhode Island

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U. S. Army Transportation
Research and Engineering Command,
Fort Eustis, Virginia.

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(Phase II, Evaluation of H-23C Engine Air and Lube Oil Filter System by Radioactive Tracer Techniques)

Prepared by:

FRAM CORPORATION
Providence 16, R. I.

for

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

FORT EUSTIS, VIRGINIA

HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

FOREWORD

The report contained herein discusses the contractor's efforts to evaluate an aircraft engine air and lube oil filter system utilizing an H-23C helicopter.

The efforts on the over-all project of Aircraft Engine Carburetor Air Filters are concluded with this report.

Reference is made to the previous contractual reports listed below:

Contract DA 44-177-TC-363, Study, Investigation, and Preliminary Design of a Universal Dry Type Engine Charge Air Filter Element and Installation Systems for Army Aircraft, Phases I and II, March 1957.

Contract DA 44-177-TC-495, Fabrication and Field Evaluation of a High Capacity, High Efficiency Charge Air Filter System for Army Aircraft, Phase I, June 1961, TR 61-57.

This report includes sufficient data to indicate the desirability of having a high-capacity air filter while maintaining efficient air flow. The utilization of a high-capacity, efficient air filter will limit the need for using bypass (nonfiltered) air, which is indicated not only to be extremely harmful at the time of use but also to have harmful lingering

effects for several hours. Sufficient data are also included to indicate higher efficiency for the newly developed filter over the currently used filter system.

A recommendation will be made that the U. S. Army Transportation Materiel Command review the results of this project and, if economically feasible, introduce similar high-capacity, high-efficiency filters into the Army aviation system.

FOR THE COMMANDER:

Approved by:

LEONARD M. BARTONE
USATRECOM Project Engineer

EARL A. WIRTH
CWO-4 USA
Adjutant

PREFACE

The Fram Corporation and the U. S. Army Transportation Research Command cooperated in a field study of the high-capacity, high-efficiency charge air filter system for the Army helicopter, H-23C, developed under Phase I of Contract No. DA 44-177-TC-495. The study was performed using radioactive tracer techniques which were monitored by personnel from the Health-Physics Section of Tracerlab, Inc.

Field testing was accomplished in the vicinity of the TRECOM Air Division hanger at Felker Heliport, Fort Eustis, Virginia during the months of September, October, and November, 1960. Operation and maintenance of the test vehicle was conducted under the able command of Captain William E. Hart of the Transportation Research Command Air Division.

Mr. Leonard Bartone of the Research Command Office was responsible for the continued close cooperation between the Contracting Agency and Fram Corporation in both the engineering and administrative aspects of the project.

Mr. W. E. Dowdell, Director of the Aircraft Filter Division, Fram Corporation, supervised the contractor's program. Field testing was conducted by Mr. J. W. Jackel, Project Engineer, Fram Corp.

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SUMMARY

This report covers the final phase of a study to develop, design, and field test a high-capacity, high-efficiency air filter for use on light aircraft engines. In order to obtain a rapid analysis of wear occurring at critical areas in a reciprocating engine, the use of radioactive tracer materials was employed and a mobile detection-counter circuit utilized in a rotary wing aircraft, an H-23C helicopter. It was visualized that an accelerated field study of this type would permit a cost analysis showing the savings in maintenance costs made possible by the proper application of both oil and air filtration equipment.

The effect of various filter configurations on the wear of an irradiated piston ring was measured both on a continuous basis by strip chart recording and on a total wear basis through spectroanalysis of lube oil samples. A tremendous increase in ring wear was measured during "hover flights" over extremely dusty terrain when the engine was unprotected from airborne contamination. An 80 minute flight which included ten minutes of hovering without an air filter in extreme dust produced 3 to 4 times the ring wear experienced during a 90 minute flight with filter protection. Flights following the one in which dirt was allowed to enter the induction system indicated that the effect of dust may linger for several hours after the ingestion occurs. Therefore, the proper design of the air filter system to insure adequate life characteristics so that by-passing is infrequent seems to be all important.

The air filter developed under Contract No. DA 44-177-TC-363 provides a dirt holding capacity of approximately three quarters of a pound of AC Coarse Dust without exceeding a pressure drop of 8 inches of water and includes a differential switch to signal impending bypass. Such a system should provide the performance characteristics necessary to cope with extreme dust concentration.

The study was not as comprehensive as originally planned since the trace of tin wear from a rod bearing was not discernible. Therefore, an analysis of the savings in maintenance costs realized by the proper application of air and oil filtration cannot be included with this report.

INTRODUCTION

The usefulness of air and oil filtration as a method to increase the life of internal combustion engines has been established very thoroughly during the past two decades. Vehicles operating in both ordinary and extreme environments have been capable of accomplishing more work at a more rapid rate due to the removal of incoming and inbred contaminants by the judicious application of filtration systems.

During recent years, new methods of measuring the effect of filtration on the wear rate of engine components have been developed. One such measuring device is the radioactive tracer technique which gives one the capabilities of establishing wear rate trends and of obtaining an insight into the critical periods of the "engine wear picture." The tracer method of analyzing wear phenomena has been applied several times to engine tests involving land vehicles but its application to air-borne power plants has been on a very limited basis.

This report presents the findings of a radioactive tracer wear test of critical components of a mobile power plant. An H-23C helicopter with radioactive tracer measuring equipment aboard was used as the test vehicle.

DISCUSSION

Test Procedures

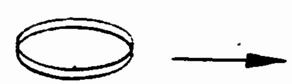
The technique of utilizing radioactive materials as tracers in studies concerning the wear phenomena occurring at critical places in mechanical devices has been utilized several times during recent years. The tracer technique has proved to be an extremely useful and versatile method when used to obtain a rapid insight into wear problems. This method of wear measurement permits the rapid accumulation of data and reveals the change in rate of wear under various operating conditions. Although the rudiments of nuclear physics will not be discussed in this report, the basic "picture" of a radioactive tracer wear study may be depicted as shown in Figures 1 and 2.

In order to learn more about the wear going on in critical areas of an internal combustion engine, two engine components were irradiated in an atomic pile. In this particular case, a piston ring and a connecting rod bearing insert from a helicopter engine were irradiated with neutrons producing among other isotopes, Cr^{51} in the ring and Sn^{113} in the bearing insert. Through the utilization of a detector, a discriminator, and a ratemeter as indicated schematically in Figure 3, a wear study was performed under field operations.

The design of the detector mount including any associated shield components must be carefully planned to provide a controlled temperature level within this critical area of the counting system. It is suggested that an oil temperature of 90°F. (plus or minus 5°) be maintained if consistent measurements are to be expected in a wear analysis of this type.

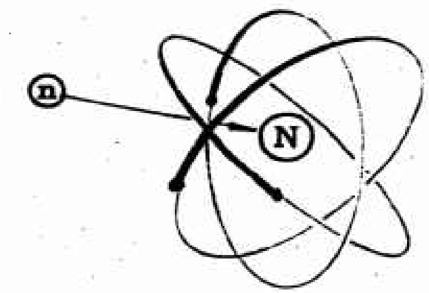
As soon as the land test vehicle produced and reproduced valid wear information, the equipment was transferred to the helicopter as shown in Figure 4. The air-borne study was intended to be much more comprehensive than the land calibration run since it included the scrutiny of wear at two points in the engine and therefore, required the use of a discriminator in the electronic counting circuit.

1. A part, in this case a piston ring, is sent to be irradiated in an atomic pile.

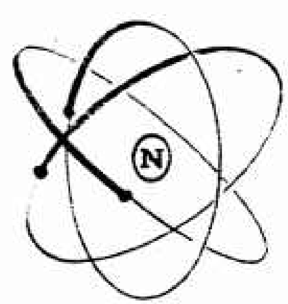


2. In the atomic pile, the part is bombarded with neutrons. Neutrons are part of an atom nucleus.

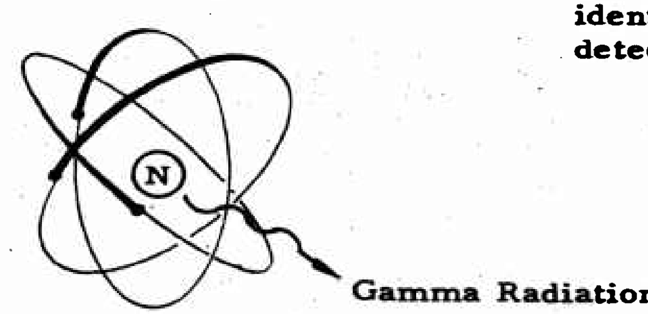
3. When the neutrons collide with the atoms of the piston ring metal, a change in the orientation of the protons and neutrons in the nucleus of the metallic atoms takes place.



4. An atom so affected is then unstable for there is a tendency for the unstable nucleus to seek a normal condition. This instability is a form of radioactivity.



5. When the disorientated neutron or proton regains its normal state, the energy which went into causing the original displacement is released by the atom. This energy is released as electromagnetic radiation called gamma rays.



6. These changes take place in a well defined manner. Therefore, one can use the energy releases to detect the presence of minute quantities of the radioactive metal. Also, because the energy released by one metal is of a different value or characteristic from that of another metal, it is possible to identify the small quantities detected.

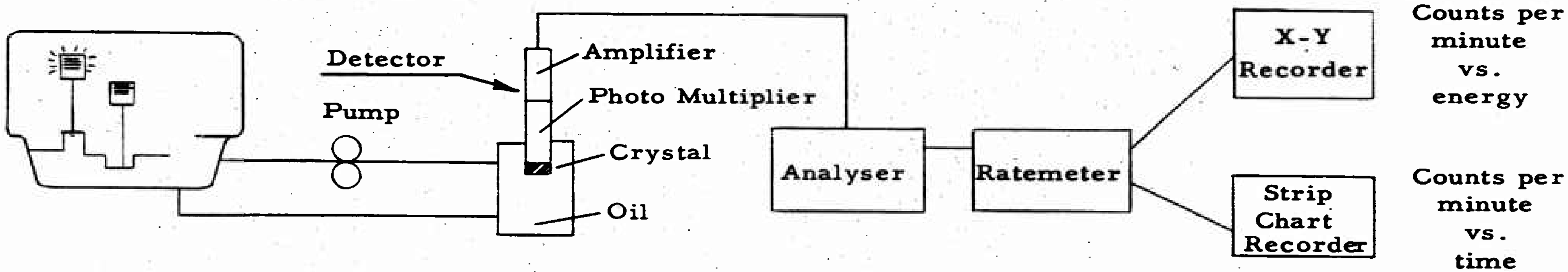
METHOD OF MEASURING ENGINE WEAR USING RADIOACTIVE TRACERS

Figure 1

7. The radioactive piston ring is placed in an engine. As it wears, small quantities of the metal are washed into the lube oil. Not all of these worn off particles are radioactive but enough are so that their presence in the oil can be detected and the amount measured.

8. To make the measurement of wear particles present, the oil is pumped continuously from the crankcase through a counter well. A detector is mounted in the well. The detector is composed of a crystal, a photo multiplier and an amplifier.

9. When a gamma ray strikes it, the crystal emits light. The photo multiplier senses the light and converts that signal to an electrical pulse. The pulse is strengthened in the amplifier.

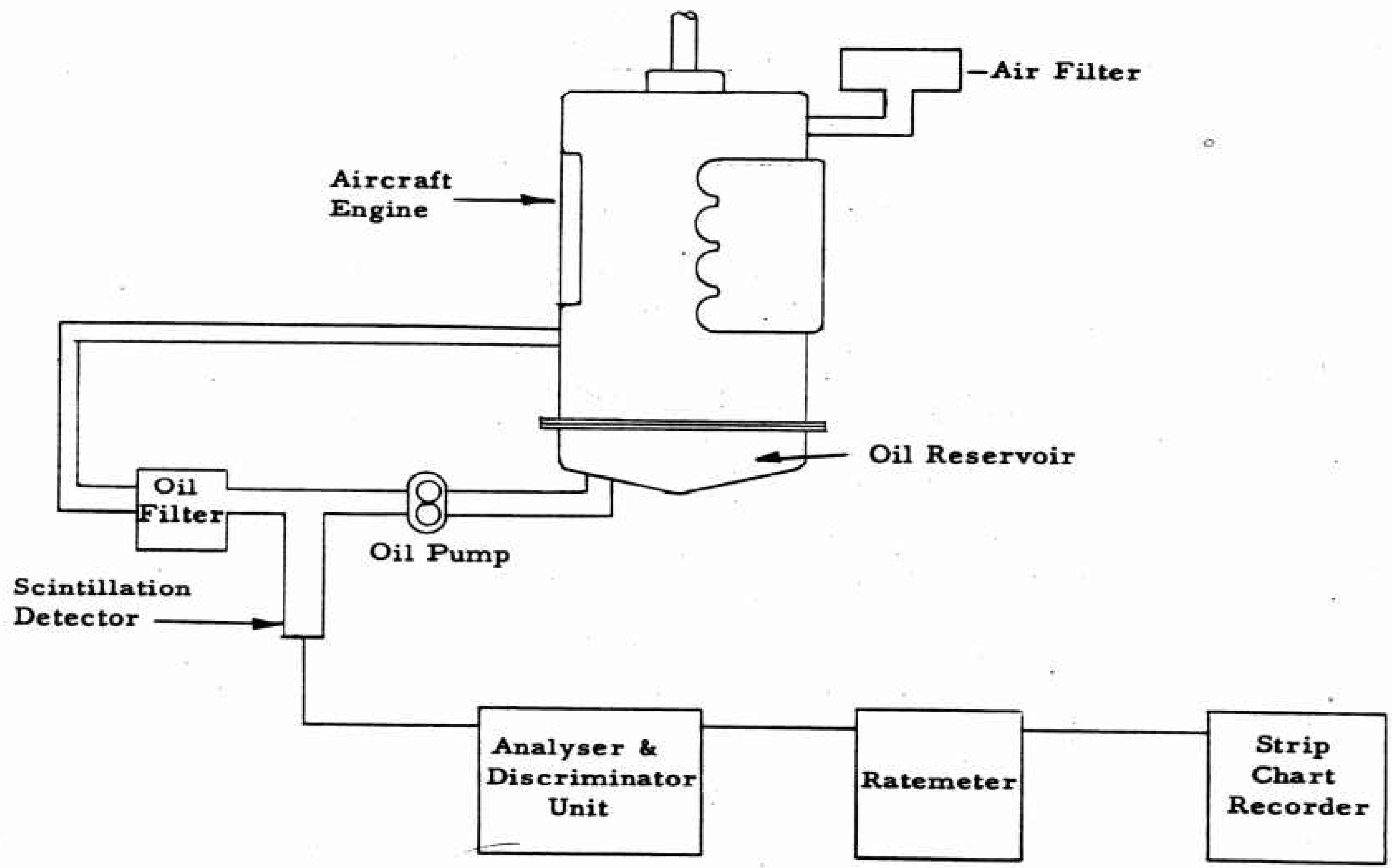


10. The pulses from the detector are sent to an analyser. This electronic device senses the amount of energy in the gamma ray which caused each pulse so that the particle of metal from which the gamma ray came can be identified.

11. The analyser is followed by a ratemeter which counts the pulses -- up to 1,000,000 per minute if necessary.

12. This information, that is the number of pulses per minute and the energy level of each pulse, is displayed on meters and fed to recorders for analysis by the engineers conducting the tests. One type of recorder shows the proportion of each radioactive element present in the oil by plotting counts per minute against energy level. The other type of recorder plots counts per minute against time to give us the rate at which wear is taking place.

Figure 2



Schematic Diagram of Instrumentation For Radioactive Tracer Wear Study on H-23C Helicopter

Figure 3

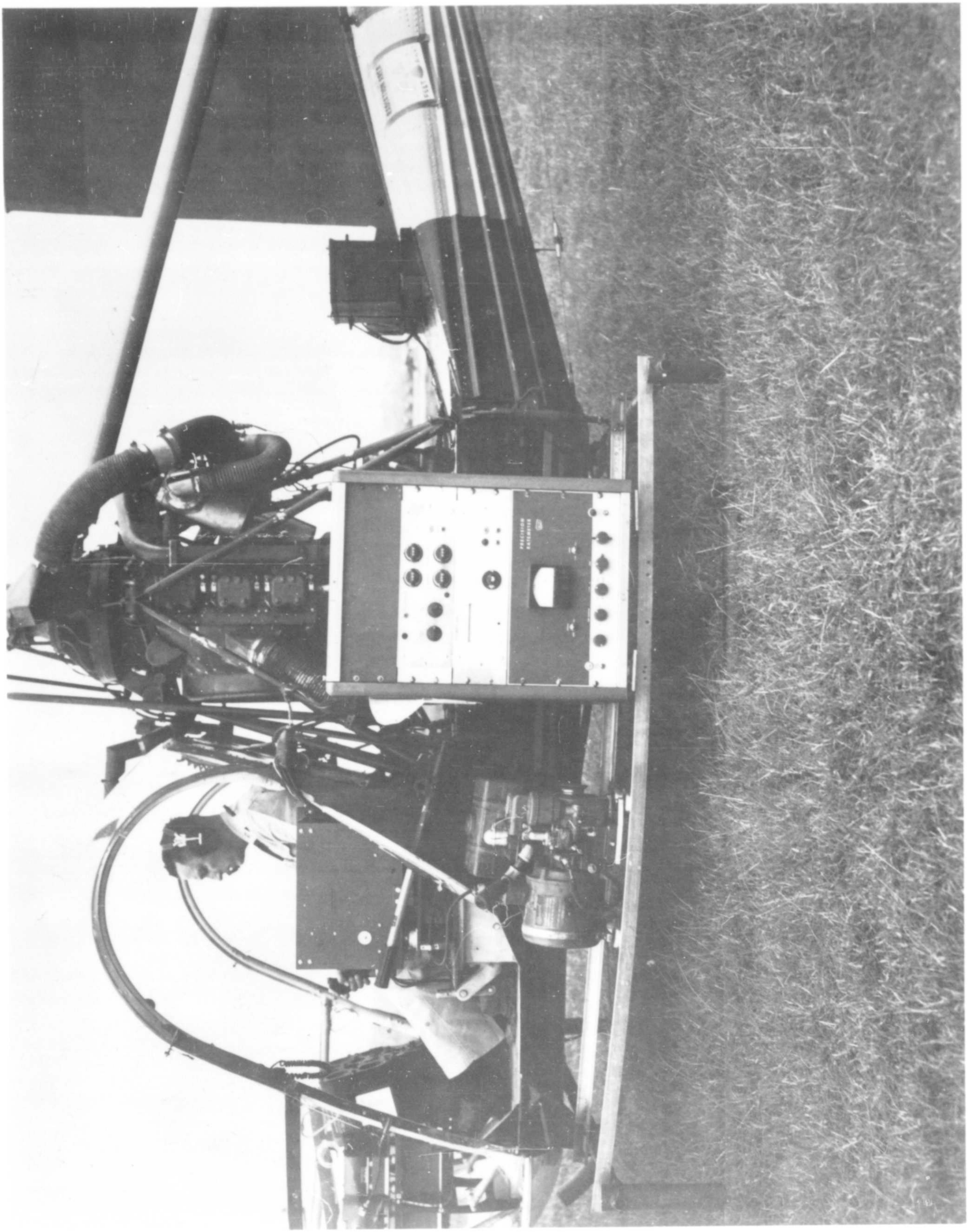


Figure 4. H-23C Helicopter Showing Radioactive Tracer Measuring Equipment and Associated Power Supply

As mentioned before, isotopes of chromium (piston ring) and tin (bearing insert) were selected to be the "tracers" as wear developed in the engine of a hovering helicopter. Former investigations concerning wear of internal combustion engines have established the importance of air filtration in reducing "top" ring wear and lube oil filtration in the reduction of connecting rod bearing wear. Therefore, the decision to use these two engine components in a study of this type was considered to be reasonable.

The transition of the wear tests from the land vehicle to the aircraft turned up some new and challenging problems which had to be solved before the flight test program could be initiated. For example, the aircraft wear study was outlined to encompass piston ring wear and rod bearing wear. The simultaneous study of two isotopes requires the careful choice of elements so that after irradiation these elements will produce distinct pulses on the energy spectrum. If the two (or more) tracers are separated on the energy spectrum, then it is a relatively easy task to discriminate between the emission of each tracer. However, it is equally important to insure that the tracer elements do not predominate in both components under analysis. If the Cr^{51} isotope utilized in this study occurred in both the ring and the bearing, no definite conclusions could be made as to where the chromium wear was occurring.

It is also important in a study of this type to utilize parts which represent actual production engine components. Therefore, a piston ring and rod bearing from the helicopter engine under study were secured and an analysis was made to determine the most propitious choice of tracer elements. Scrapings were taken from the bearing and ring wear surfaces and their spectrums were plotted. Both sample scrapings showed traces of Sb^{124} and Fe^{59}. The choice of Cr^{51} was clearly indicated as it definitely stood out in the "ring scraping spectrum" and was not involved in the bearing scraping analysis. The choice of Sn^{113} as the bearing wear tracer seemed appropriate since it was not present in the ring sample spectrum and it yielded the highest count rate in the bearing sample.

Unfortunately, the Sn^{113} isotope could not be adequately traced through the use of the measuring circuit indicated in Figure 3. The wear of the tracer element, Cr^{51}, in the piston ring completely overshadowed the wear of the tin isotope from the bearing and therefore, did not allow the definition of the latter tracer through use of the portable detector circuit.

It should be pointed out that the design of the tracer counter and measurement circuit required extreme care to insure the portability of the complete equipment. The aircraft used for this wear study has a maximum gross weight capability of only several hundred pounds above its empty weight. Therefore, all of the test equipment including the protective lead shield covering the counter well was designed with "minimum weight" as a primary consideration. Figures 4, 5, 6, and 7 show the helicopter with the experimental equipment in place and illustrate the extreme requirements for the insurement of safety and portability.

Any work involving the use of radioactive materials requires the establishment of rigid "housekeeping" procedures and the enforcement of proper waste disposal methods. Even though the level of radioactivity is low (such as in this study), the monitoring of the activity is very important and is required by both Federal and State regulations.

A check list of some of the more important facets of a well-organized program follows:

1. A. E. C. License.
2. Health-Physics consultants.
3. Establishment of isolated storage areas properly identified.
4. Installation protective equipment (clothing, tongs, shipping pigs, etc.).
5. Film badges and dosimeters.
6. Waste disposal.

Figure 5. Radioactive Tracer Flight Test H-23C Helicopter

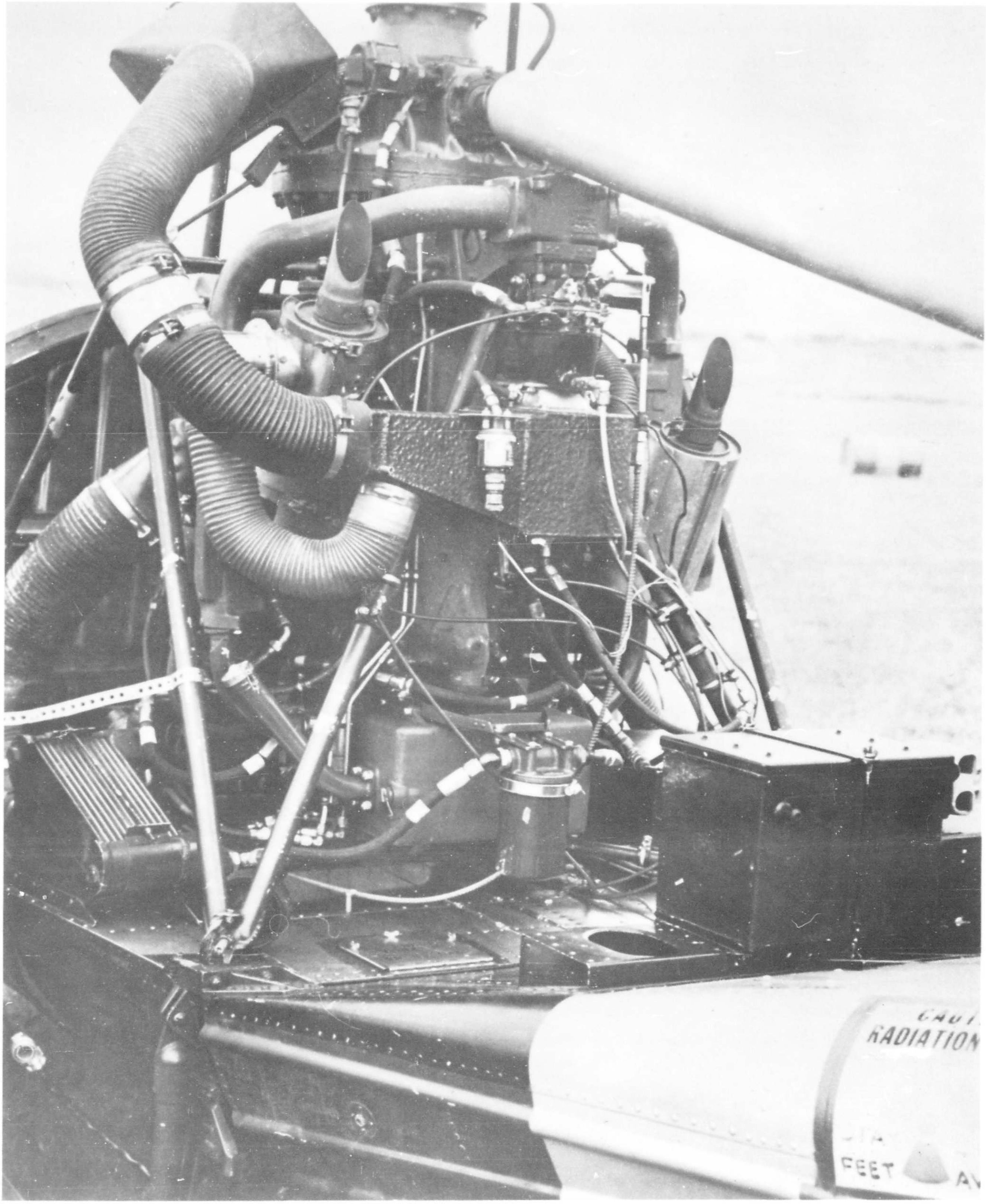


Figure 6. Engine Air Filter and Lube Oil Filter Installation on H-23C Helicopter

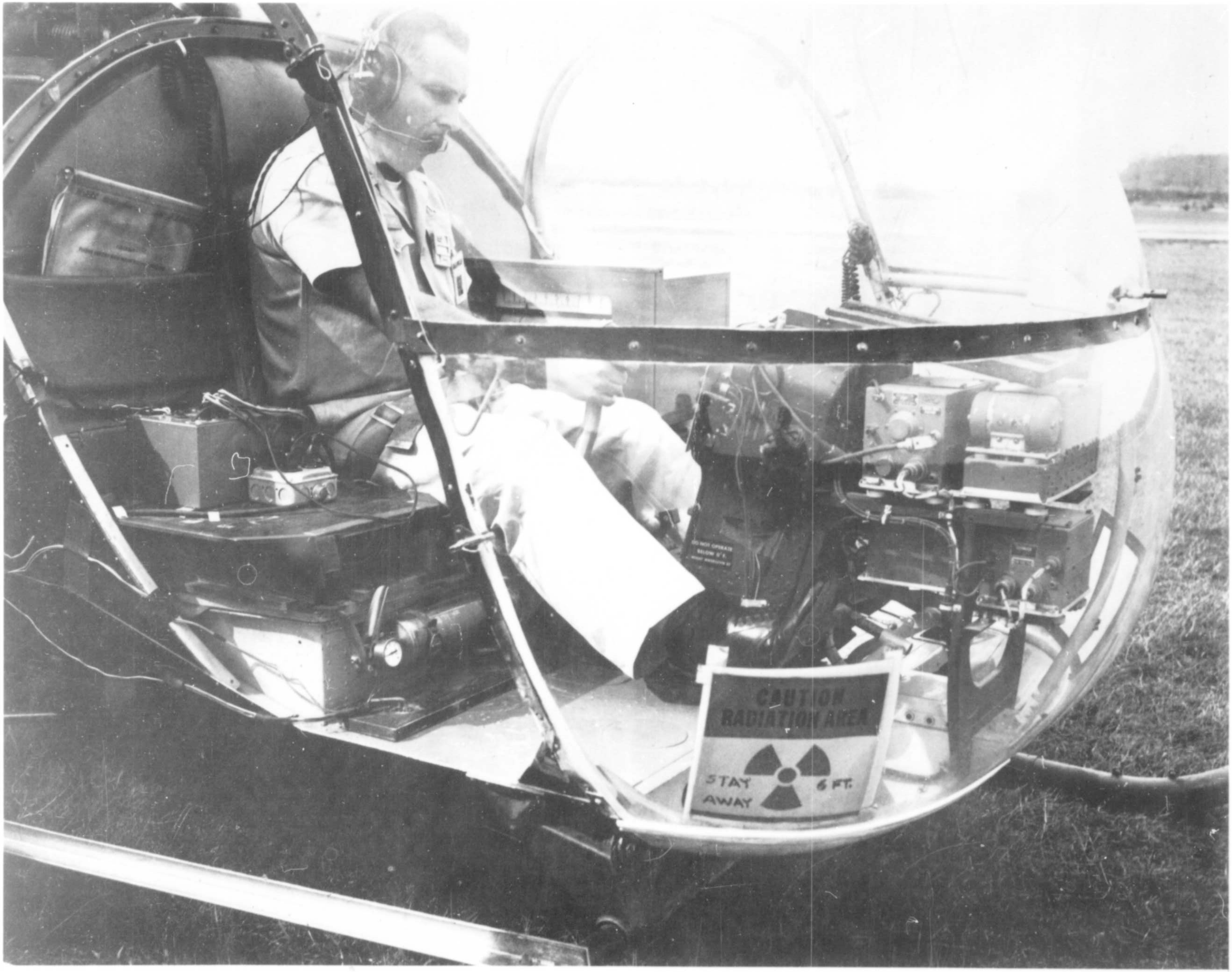


Figure 7. H-23C Cockpit with Recording Equipment in Position

Engine Wear Study

The flight test program to determine the effect of filtration on vital engine parts commenced on 3 October 1960 and was concluded on 7 November 1960. Several combinations of "high-capacity, high-efficiency" air and lube oil filter systems were utilized to permit as broad an interpretation of data as could be expected in an accelerated test of this type. The wear data, as presented in Figures 8, 9, and 10 of this report, indicate the versatility and usefulness of this type of wear analysis.

As previously mentioned, all of the useful data obtained in this study is relative to the measurement of the wear of the top piston ring. The attrition of the chromium from the ring was many times more severe than the wear of the tin from the bearing surface. This fact, coupled with the proximity of the two isotopes on the energy spectrum, made it impossible to detect and discriminate between the Cr^{51} and the Sn^{113}. However, some significant facets of engine wear in rotary wing aircraft were brought out and substantiated by this wear study.

In order to determine the "complete wear picture", two methods of measuring the radioactive wear particles were employed. First, a continuous monitoring of the radioactivity in the lube oil system was accomplished through the use of the strip chart recorder. In addition, samples of the lube oil were extracted after each flight and were analyzed for radioactive particle content. A sample calculation of total ring wear in milligrams from the post flight oil analysis for Flight II-1 (Table A) follows:

1. Oil sample spectroanalysis measured a radioactive count of 1.67×10^2 disintegrations per minute per milliliter of engine oil.

2. This activity, $1.67 \times 10^2 \ \frac{DPM}{ml}$, may be converted to milligrams of ring wear.

(a) 1 microcurie of radiation = 2.2×10^6 DPM

(b) $$\left[1.67 \times 10^2 \ \frac{\text{DPM}}{\text{ml}}\right]\left[\frac{1}{2.2 \times 10^6} \ \frac{\mu\text{C}}{\text{DPM}}\right] = .76 \times 10^{-4} \ \frac{\mu\text{C}}{\text{ml}}$$

(c) The activity is now represented as $.76 \times 10^{-4} \ \frac{\mu\text{C}}{\text{ml}}$

(d) Taking into consideration the decay rate of Cr^{51}(half life = 27 days), it may be shown that 1 microcurie Cr^{51} = 2.02 mg Cr^{51}

(e) $$\left[.76 \times 10^{-4} \ \frac{\mu\text{C}}{\text{ml}}\right]\left[2.02 \ \frac{\text{mg}}{\mu\text{C}}\right] = 1.535 \times 10^{-4} \ \frac{\text{mg}}{\text{ml}}$$

(f) Since the oil system of the H-23 contained 12 quarts of oil or 1.1355×10^4 ml of oil:

$$\text{Total wear} = \left[1.535 \times 10^{-4} \ \frac{\text{mg}}{\text{ml}}\right]\left[1.1355 \times 10^4 \ \text{ml}\right]$$

$$= 1.743 \text{ mg of chromium}$$

Table A lists the total wear determined from oil analysis of the various flights.

The analysis of ring wear during flights II-1, II-2, and II-3 is tabulated in Tables B, C. D. E. F, and G. This series of flights compares the effect on piston ring wear of varying the type and extent of filtration on the engine. Table B lists the total wear during each of the three flights as determined by oil sample analysis. The wear measured when no filters are present in the system is approximately 10 percent higher than when filtration protection is provided.

The strip chart data was condensed and is presented in Graph Figure 8 and Tables C, D, and E. The graph is a plot of activity versus flight time and supplies an indication of the wear picture. A considerable portion of the wear during the flight was due to start-up wear. Figures 8 and 9 indicate that the start-up wear for the system without filters was less than the start-up wear for the systems with filters. Start-up wear is a condition that is dependent upon several factors, among which are: environmental conditions, fuel and lubricant quality, and type of service. Of the items listed above, only the ambient temperature was recorded during the flight tests. The ambient temperature was 59°F. on 21 October 1960

TABLE A

OIL SAMPLE ANALYSIS

Flight No.	Flight Duration (Minutes)	Terrain	*Filter Configuration	Ring Wear (mg)
I-1	90	Grass	A	2.262
I-2	90	Grass	E	2.936
I-3	90	Grass	B	2.546
II-1	90	Grass	A	1.743
II-2	90	Grass	E	1.929
II-3	120	Grass	B	1.752
III-1	35	Grass	B	
	10	Extreme Dust	E	
	35	Grass	B	8.417
IV-1	120	Grass	D	6.881
IV-2	120	Grass	C	4.885

*A - High-Capacity, High-Efficiency Air Filter and Full Cellulose Fiber Oil Filter.

B - High-Capacity, High-Efficiency Air Filter and No Oil Filter.

C - Original Equipment Air Filter and Oil Filter.

D - Original Equipment Air Filter and No. Oil Filter.

E - No Filters.

TABLE B

OIL ANALYSIS

Flight No.	Filter Configuration	Duration of Flight (Minutes)	Total Ring Wear (mg)
II-1	A	90	1.742
II-2	E	90	1.929
II-3	B	120	1.752

TABLE C

TOTAL WEAR - STRIP CHART DATA

Flight No.	Filter Configuration	Duration of Flight (Minutes)	Wear Rate
II-1	A	90	1300 cpm/90 min.
II-2	E	90	1510 cpm/90 min.
II-3	B	120	1340 cpm/120 min.

TABLE D

START-UP WEAR - STRIP CHART DATA

Flight No.	Filter Configuration	Wear During Original 10 Min. of Flight
II-1	A	680 cpm
II-2	E	535 cpm
II-3	B	805 cpm

TABLE E

EQUILIBRIUM WEAR RATE - STRIP CHART DATA

Flight No.	Filter Configuration	Equilibrium Wear Rate
II-1	A	6.9 cpm/min.
II-2	E	18.2 cpm/min.
II-3	B	5.0 cpm/min.

TABLE F

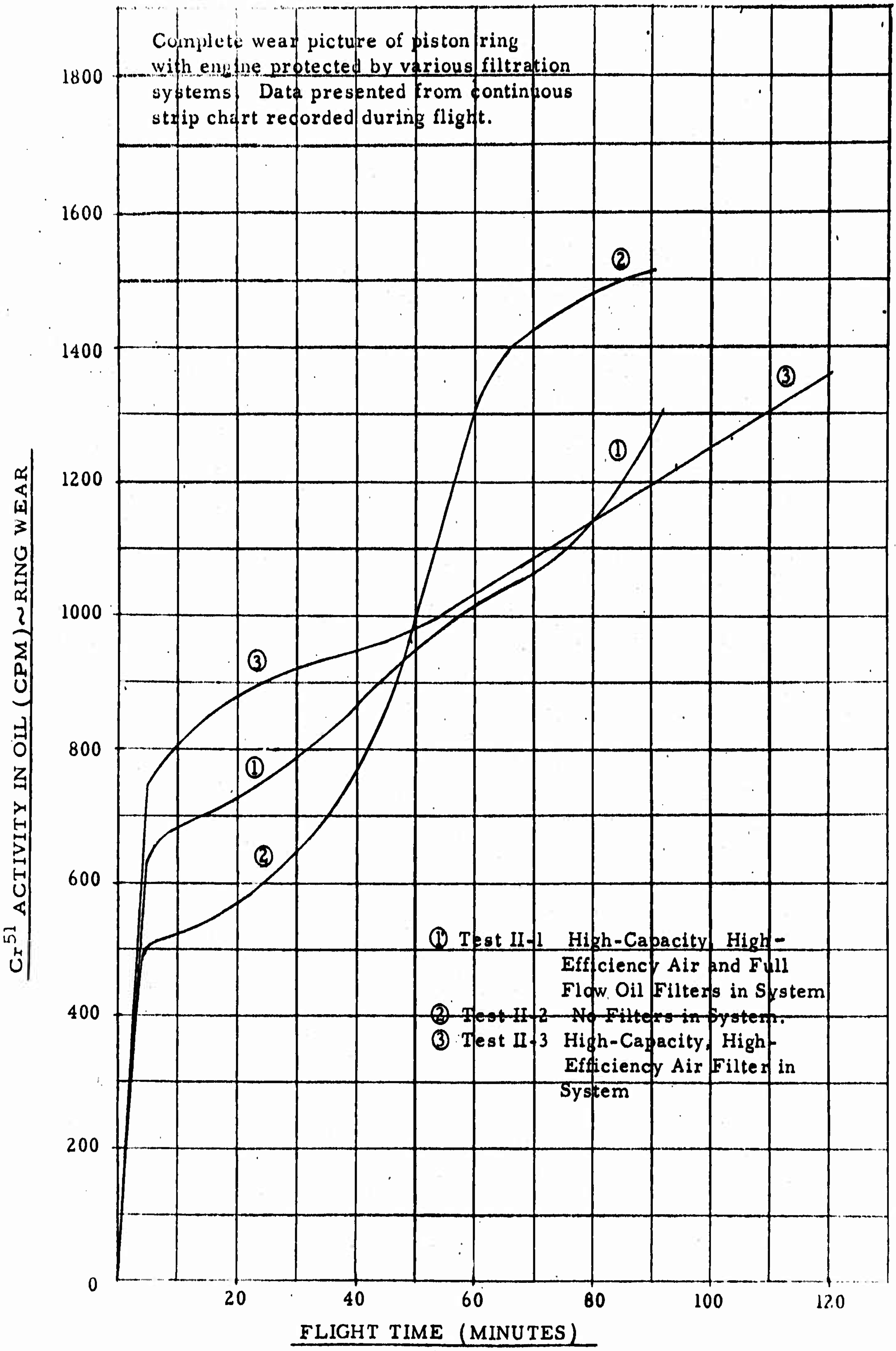
COMPARISON BETWEEN OIL ANALYSIS DATA AND CONTINUOUS STRIP CHART GRAPHS

Flight No.	Filter Configuration	Wear (mg) Oil Analysis	Strip Chart Increase in Activity
II-1	A	1.743	1300 cpm
II-2	E	1.929	1510 cpm
II-3	B	1.752	1340 cpm

TABLE G

RELATIVE WEAR WITH NO FILTER SYSTEM AS BASE

Flight No.	Filter Configuration	Oil Analysis	Strip Chart
II-1	A	$\frac{1.743}{1.929} = .903$	$\frac{1300}{1510} = .860$
II-2	E	$\frac{1.929}{1.929} = 1.000$	$\frac{1510}{1510} = 1.000$
II-3	B	$\frac{1.752}{1.929} = .907$	$\frac{1340}{1510} = .887$



Complete wear picture of piston ring with engine protected by various filtration systems. Data presented from continuous strip chart recorded during flight.
1800
1600
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
Cr^{51} ACTIVITY IN OIL (CPM) ~ RING WEAR
FLIGHT TIME (MINUTES)
① Test II-1 High-Capacity, High-Efficiency Air and Full Flow Oil Filters in System
② Test II-2 No Filters in System.
③ Test II-3 High-Capacity, High-Efficiency Air Filter in System

Figure 8

when flight test II-3 was performed, and 68°F. for tests II-1 and II-2 on 18 and 19 October 1960. It would be difficult to estimate the effect of the temperature on the start-up wear, when many other factors can also influence this condition. Table C lists the total activity increase for the duration of each of the flights. Table D lists the start-up wear and Table E, the equilibrium wear rate. The equilibrium wear rate is represented as the wear occurring after start-up influences have ceased. It provides a true picture of the filter effectiveness in a system. The equilibrium wear rate is determined from Graph Figure 9 by drawing a straight line on each curve that best represents the slope of the curve throughout the test, disregarding start-up wear. Table E illustrates that the equilibrium wear rate is approximately three times as great for the system without filters as for those with air and oil filters.

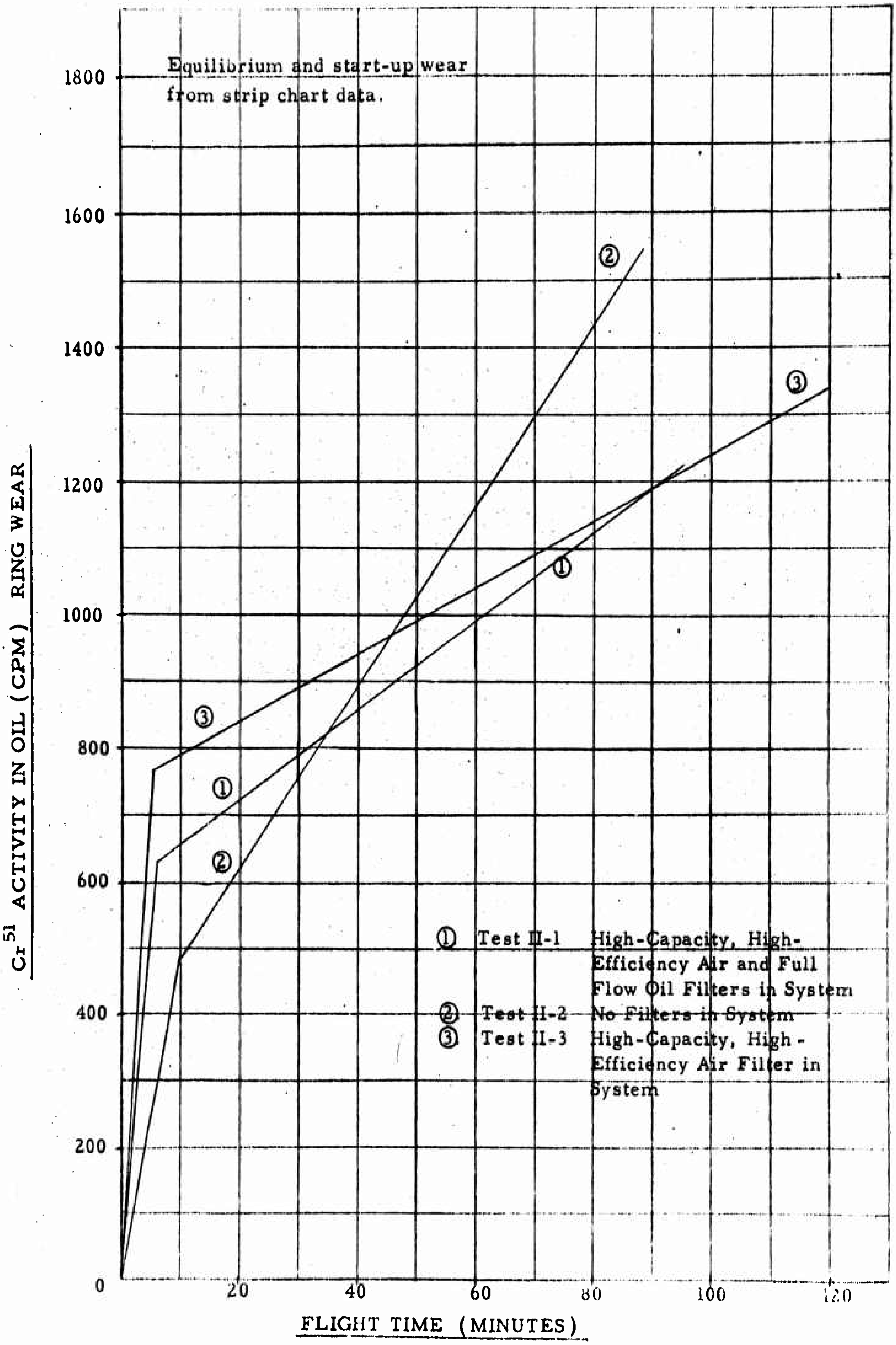
Another check is to compare the total increase in count for each of the three flights from strip chart data with the oil analysis data. The increase in count for a given flight will be proportional to the total wear which is represented in the oil data. Table F lists this data and Table G compares the relative wear with the no filter wear as the base. From Table G, it can be noted that the strip chart and oil sample wear agree closely.

The importance of proper air filtration on engines subjected to extreme environmental conditions is amplified by the data presented in the plot of wear versus flight time (Figure 10). This chart represents the change in rate of ring wear during an eighty (80) minute hover flight. This flight could be outlined as follows:

1. A 35 minute hover period over a grass terrain with the engine protected by a high-capacity, high-efficiency air filter but with no lube oil filter in the system.

2. A 10 minute continuous hover over a loose dust terrain with the air filter bypassed.

3. Another 35 minute hover over a grass terrain with the engine's induction system again protected by an air filter.



Equilibrium and start-up wear from strip chart data.
Cr^{51} ACTIVITY IN OIL (CPM) RING WEAR
1800
1600
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
FLIGHT TIME (MINUTES)
① Test II-1 High-Capacity, High-Efficiency Air and Full Flow Oil Filters in System
② Test II-2 No Filters in System
③ Test II-3 High-Capacity, High-Efficiency Air Filter in System

Figure 9

Effect of Bypass Air on
Engine Wear Under Extreme
Dust Concentrations

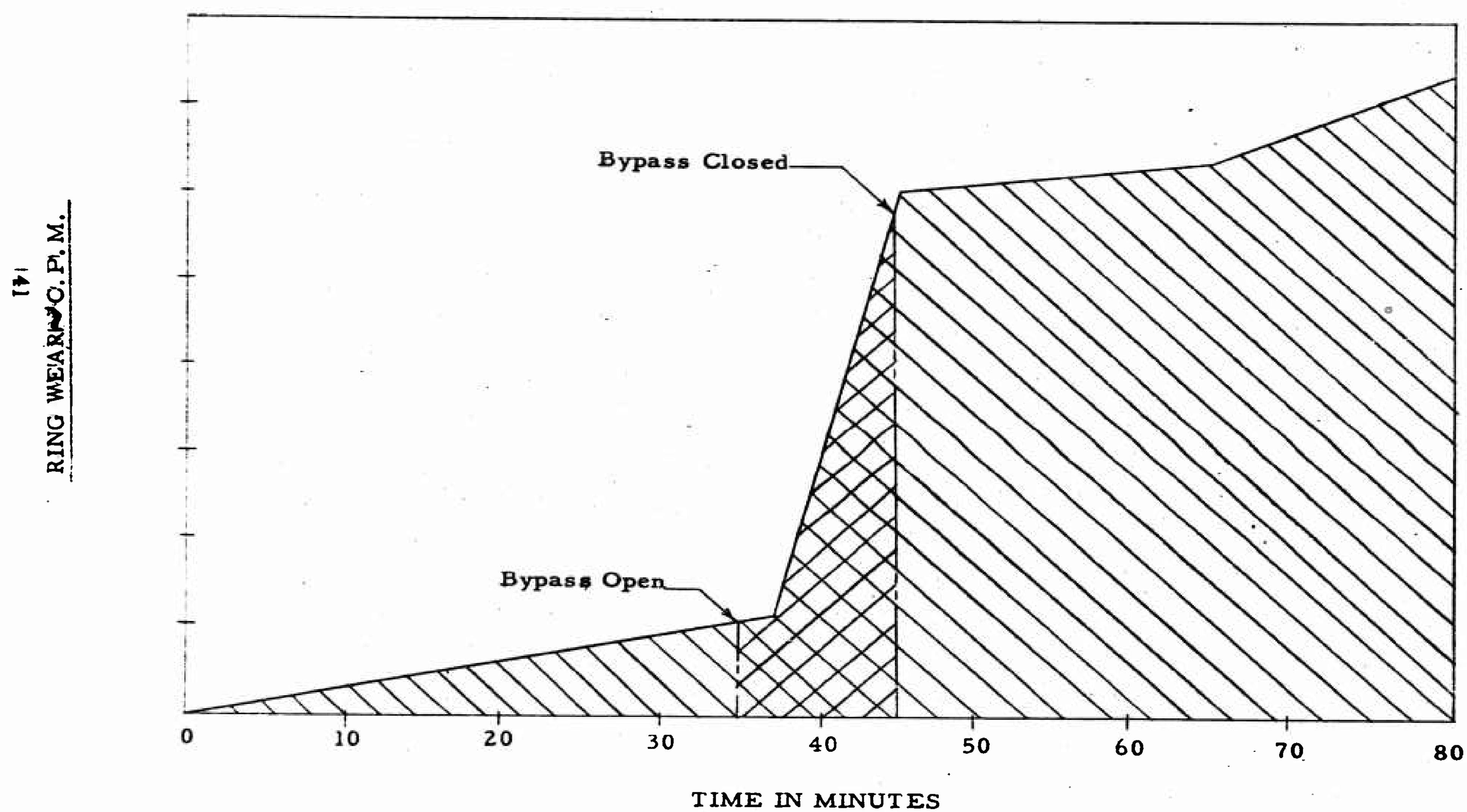


Figure 10

The rate of wear of the piston ring during the first 35 minutes of the flight was constant. The effect of the opening of the air filter bypass door (Reference: TREC Technical Report 61-57) did not show up until the end of 38 minutes at which time the slope of the wear curve took a drastic change. In other words, it took about 3 minutes after the opening of the bypass air door in the filter housing before evidence of an increase in ring wear showed up in the oil system.

The recovery of wear rate after closing the bypass and returning to the grass terrain occurred very quickly as shown in Figure 10. The rate of wear re-established the trend of the first 38 minutes of the flight and then showed a definite increase about the 65 minute mark.

It is felt that this change in wear rate near the end of the flight with the air filter in the system may be attributed to the "linger effect" of the contaminant introduced into the system during the hover over dusty terrain. Obviously, there are many places in which air-borne contaminants, especially fine dust particles, could be trapped for various lengths of time after having entered the induction system. During the bypass period, a tremendous quantity of dust particles were permitted to enter the engine. Many of these particles passed through the engine and the evidence of their contribution to ring wear is emphatic. However, undoubtedly some of these particles were sidetracked along the induction path and remained to provide further damage as indicated by the increase in slope of the wear curve near the end of the flight.

Figure 10 brings out some of the ramifications of induction air filtration that could only be learned from an instantaneous study of this type. The number of times an air filter must be bypassed on take-off or during hover appears to be of vital interest to anyone associated with engine maintenance. The proper design of the entire induction system, including a low-restriction, high-capacity air filter, is of paramount importance. If the filter is designed to provide optimum air flow characteristics, then the bypass condition will not be significant. For example, under Phase I of this contract (Reference: TREC Technical Report 61-57) and the two phases of Contract No. DA 44-177-TC-363, a comprehensive program was planned and carried out to provide a high-capacity, high-efficiency air filter with low initial restriction. Great care was taken to insure an optimum air flow pattern within the filter housing so as to circumvent power losses and to minimize the number of times the air filter would have to be removed from the induction system. The importance and significance of an optimum design air filter for a rotary wing aircraft can be appreciated when facts such as indicated in Figure 10 are studied.

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The analysis of engine oil samples from flights IV-1 and IV-2 indicate a much higher amount of wear with the original equipment filters in the system than with the newly developed high-capacity air filter and full flow lube oil filter. However, since these last two tests followed the bypass test (Flight III), it is felt that the effect of extreme dust ingestion were still being felt by the engine even though the engine was flushed after each test.

It must be recognized that the radioactive tracer technique provides an insight into instantaneous happenings within the system under analysis and is, therefore, a very powerful and versatile wear measurement tool. However, the idiosyncrasies and limitations of an accelerated study of this type should also be recognized. For example, the influence of the environmental conditions from day to day on the wear measurements must be analyzed. A one hour helicopter flight over the same terrain on consecutive days may not result in the same wear pattern. Variables such as weather, temperature, engine orientation, and even pilot procedures may cause wide differences in measurements. The judicious choice of measuring equipment, test vehicle, and test site are of prime importance in obtaining valid and meaningful results. The variables which can be controlled must be stringently controlled so that useable data may be obtained in a minimum of time.

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